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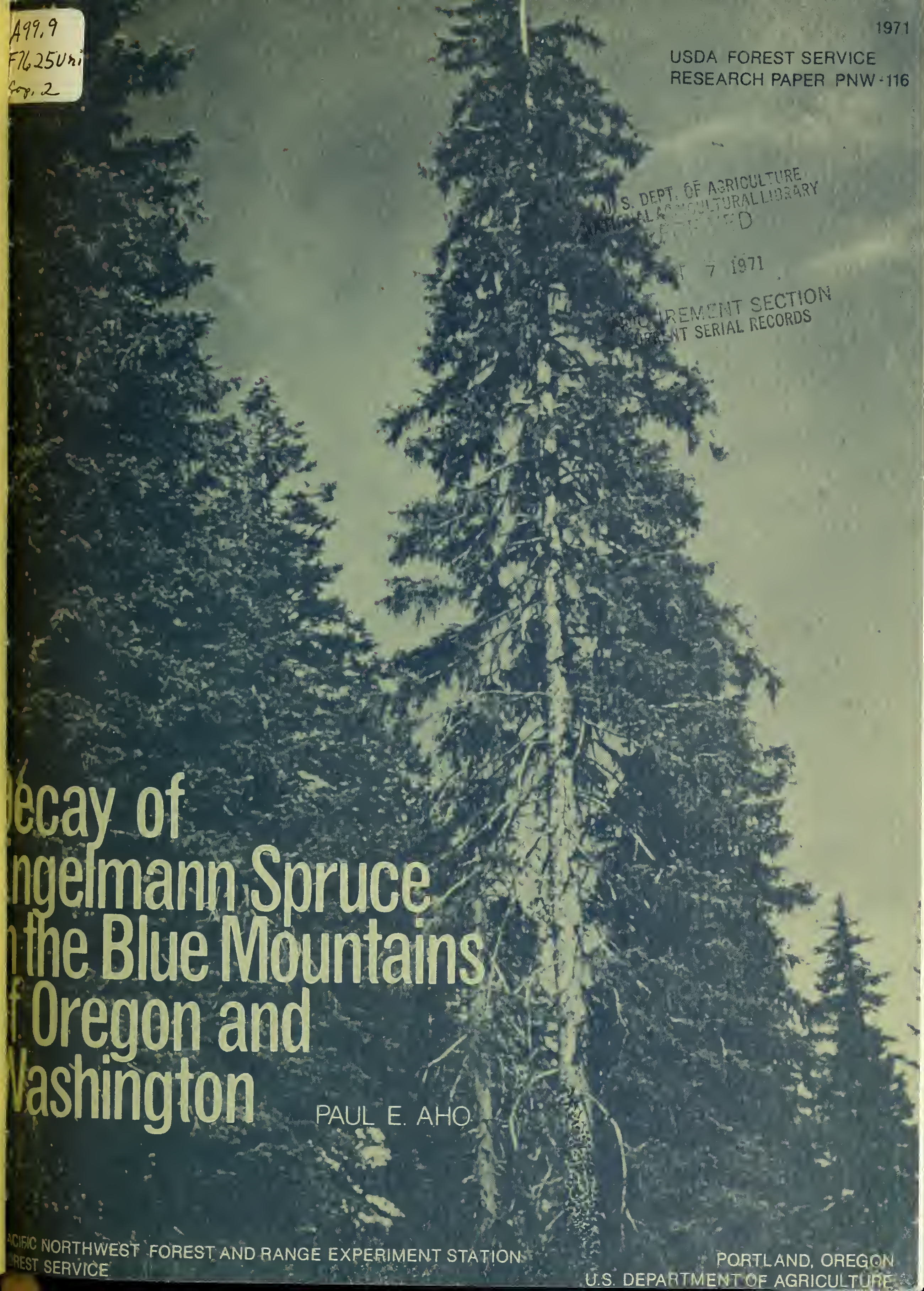

ecay of ngelmann Spruce n the Blue Mountains f Oregon and Vashington

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CONTENTS

Keywords: Decay fungi (wood), defect indicators (wood quality), fungi (forest damage).

SUMMARY

A total of 292 Engelmann spruce were dissected and examined for decay and other defects in seven areas in the Blue Mountains of southeastern Washington and northeastern Oregon. Decay on a cubic-foot basis was 3.3 percent for pole trees and 5.4 percent for sawtimber. Defect loss in sawtimber spruce amounted to nearly 12 percent of the gross merchantable board-foot volume. Decay varied among study areas and could not be explained on the basis of age differences.

A possible cyclic relationship was indicated between decay and age and diameter, rather than a progressive increase in decay with increasing age and diameter.

Eleven fungi were associated with 75 percent of all infections and those resulted in 80 percent of the total decay cubic volume. *Polyporus tomentosus* var. *circinatus* alone caused 44 percent of the individual infections; however, only 10 percent of the decay cubic volume was associated with this fungus. Trunk rotting fungi were responsible for only 11 percent of all infections, but these caused nearly 30 percent of the decay cubic volume. *Stereum sanguinolentum* and *Fomes pini* were the two most important trunk decaying fungi. Roots were entrance courts for 74 of 109 individual fungal infections. All *P. tomentosus* var. *circinatus* infections took place through the roots.

Defect indicator factors are given as: (1) percentages of tree gross merchantable cubic- and board-foot volumes, and (2) average length deductions below and above indicators with flat percentage factors for hidden defect.

INTRODUCTION

Engelmann spruce (*Picea engelmannii* Parry) is an important component of upper-slope forest types[1] in many areas in the Blue Mountains of northeastern Oregon and southeastern Washington. More than 5 percent of the total Scribner board-foot volume and total growing stock (cubic volume) of all species in the Blue Mountains is Engelmann spruce.[2] Logging and management activities have been increasing rapidly in many of these mature or overmature stands. Defect information, particularly extent of decay losses in standing trees, is essential for obtaining reliable estimates of sound volumes used in forest management.

In 1959, the Pacific Northwest Forest and Range Experiment Station began a heart rot-defect study in the upper-slope forest types in the Blue Mountains. Guides for estimating defect in grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), western larch (*Larix occidentalis* Nutt.), and Engelmann spruce have been published (Aho 1966). This paper provides a more detailed account of defect in Engelmann spruce and the fungi associated with decay.

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[1] Upper-slope forest types are defined here as commercial stands of mixed conifers at elevations above the ponderosa pine type.

[2] Forest Survey data, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

LITERATURE REVIEW

Engelmann spruce decay studies have been carried out in the Rocky Mountains of Colorado and Alberta, Canada. Hornibrook (1950) presented means for estimating defect in standing mature and overmature Engelmann spruce, lodgepole pine (*Pinus contorta* Dougl.), and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) in Colorado. Most cull was associated with the following defect indicators in order of their importance: conks, swollen knots, hollow sound produced when tree is hit with an axe, decay on increment core, crook and sweep, fire scars, forks, cankers, frayed branch stubs, lightning scars, frost and wind cracks, and top injuries. Decay caused 87 percent of the total defect in the three species. Eleven species of fungi were listed, but *Fomes pini* Brot. ex Fr.) Karst., *Polyporus circinatus* Fr., and *Coniophora cerebella* Pers. were responsible for about 90 percent of the decay volume. The trunk rots accounted for 73 percent (*F. pini* alone caused 64 percent) and root and butt rots 14 percent of the total defect. Various indicators and decays were described. Recommended scaling practices were given but not for individual tree species.

Etheridge (1956) studied decay of subalpine spruce species, including Engelmann, white (*Picea glauca* var. *albertiana* (S. Brown) Sarg.), and black (*P. mariana* (Mill) B.S.P.) spruces on the Rocky Mountain Forest Reserve in Alberta. Although approximately half of the total infections were butt rots and half were trunk rots, 70 percent of the decay losses were attributable to trunk rotting fungi. Nearly 94 percent of the total decay was associated with fungi which produce white rots. Most trunk rot was caused by *F. pini*, *Stereum sanguinolentum* (Alb. and Schw. ex Fr.) Fr., and *Peniophora septentrionalis* Laurila, while *Polyporus circinatus* var. *dualis* Peck and *Flammula connissans* Fr. were associated with the majority of root and butt rots.

Decay in subalpine spruce averaged 20 percent of the gross merchantable volume and ranged from approximately 1 to 42 percent among sample areas (Etheridge 1958). Decay increased with increasing tree age and diameter at breast height (d. b. h.).

Hinds and Hawksworth (1966) studied indicators and associated decay in Engelmann spruce in Colorado. *F. pini* punk knots or conks, broken tops, dead top with adjacent dead rust brooms, basal wounds, dead rust brooms, dead leaders, frost cracks, all forks, two trees joined at base, spike tops, and trunk wounds were indicators consistently associated with decay. These indicators were divided into three classes and cull factors developed for each grouping. Trunk rot fungi were associated with 88 percent of the total decay. *F. pini* was responsible for the greatest number of infections and greatest amount of cull. It also was the only fungus associated with all of the reliable indicators previously mentioned. *Stereum sanguinolentum* and *S. sulcatum* Burt. were other significant causes of white trunk rot. *Fomes nigrolimitatus* (Rom.) Egel., *Pholiota alnicola* (Fr.) Singer, *Polyporus tomentosus* Fr. var. *circinatus* (Fr.) Satory & Maire, and *Corticium radiosum* (Fr.) Fr. caused the major white butt rots and *Coniophora puteana* (Schum. ex Fr.) Karst., the major brown butt rot.

METHODS

This study was made in mature and overmature upper-slope stands in the Blue Mountains of eastern Oregon and Washington. Engelmann spruce was found in seven of the 11 study areas. All 5-inch d. b. h. and larger trees were dissected and examined for decay on systematically selected 1/5-acre plots. Field methods and procedures for measuring defect have been reported

(Aho 1966) and are not repeated here except as needed for clarity.

Defect-estimating equations relating percent decay[3] (based on cubic feet) and percent defect[4] (based on board feet) to certain tree characteristics and external defect indicators were developed from multiple regression analyses for pole and sawtimber Engelmann spruce (Aho 1966). Independent variables, when the dependent variable was decay percent based on cubic feet, were tree d. b. h., age, the presence or absence of basal injuries, trunk injuries more than 1 foot long, and broken tops below merchantable top diameter. In addition, presence or absence of frost cracks was included as an independent variable when percent defect based on board feet was the dependent variable.

Samples were obtained from all decay columns in trees to determine the fungi present and the amount of decay associated with each fungus. Cultures were made by aseptically planting decayed wood chips on 2-percent malt agar in test tube slants. Fungi isolated were studied for identification by the author and Mrs. Frances Lombard, mycologist, Forest Disease Laboratory, Laurel, Maryland.

RESULTS AND DISCUSSION

A total of 292 Engelmann spruce were examined. This included 141 pole and 151 sawtimber trees 5.0- to 10.9-inch d.b.h. and 11.0 inches and over, respectively. The basic data are summarized in table 1 by study areas. The average age of all poles was 119 years; decay in these was 3.3 percent of the gross merchantable cubic volume. Sawtimber averaged 154 years; decay caused a loss of 5.4 percent of the gross merchantable cubic volume and 11.1 percent of the gross board-foot volume. Application of cull rules in effect in 1966 (log is cull if less than one-third sound) and inclusion of other defects increased board-foot defect to 11.8 percent in sawtimber.

Decay varied considerably among areas and could not be explained solely by age. For example, on the Round Mountain sale, sawtimber averaged 110 years and defect was 13.5 percent of the gross board-foot volume. On the Swamp Creek No. 2 sale, average age was 171 years, but defect was only 4.7 percent of the gross board-foot volume (table 1). Board-foot defect among study areas ranged from approximately 5 to 36 percent, whereas in Alberta the range was from 1 to 42 percent (Etheridge 1958) and in Colorado, 7 to 26 percent (Hinds and Hawksworth 1966).

Age-decay relationship.--The incidence and severity of decay usually increase with tree or stand age (Wagener and Davidson 1954). In this study, trees were grouped by 50-year age classes and percent decay determined for each class in cubic feet and board feet (fig. 1). Although there were too few trees in age classes over 200 years to draw definite conclusions, the data suggest decay may be cyclic rather than progressive.

In trees under 100 years, decay in cubic feet was negligible. It increased to 5.6 percent in the 100- to 149-year age class and decreased to 5.0 and 4.2 percent in the 150- to 199- and 200- to 249-year age classes, respectively. In the 250- to 299-year age class, decay increased to 8.1 percent, dropping to less than 1 percent at ages 300-349, and then rising to 33.6 percent in trees over 350 years old.

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[3] In cubic-foot measure, decay is the only defect.

[4] In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log is one less than one-third sound. Crook, sweep, or breakage in felling are not included in defect.

Table 1.--*Summary of basic data for Engelmann spruce study*

Study area and Ranger District	Trees 5.0- to 10.9-inch d.b.h.							Trees 11.0-inch and greater d.b.h.									
	Basis		Average			Cubic-foot volume		Basis		Average			Cubic-foot volume		Board-foot volume		
	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Plots	Trees	Age	D.b.h.	Height	Gross merchantable	Decay	Gross merchantable	Decay	All defect[1/]
	--Number--		*Years*	*Inches*	*Feet*	*Cubic feet*	*Percent*	*--Number--*		*Years*	*Inches*	*Feet*	*Cubic feet*	*Percent*	*Board feet*	*---Percent---*	
Round Mountain, Pendleton	2	6	75	8.1	61	66.7	3.6	10	46	110	18.1	85	3,209.2	5.4	15,824	11.8	13.5
Mount Nebo, Joseph	6	42	131	7.9	47	283.8	4.5	10	57	187	16.6	94	3,699.0	7.4	18,570	14.5	14.8
Abel's Ridge, Pomeroy	4	40	94	8.0	60	402.2	2.9	4	22	125	14.5	90	1,063.1	2.2	4,515	6.1	6.1
Swamp Creek No. 2, Walla Walla	4	5	152	9.3	21	52.3	8.8	4	12	171	21.9	127	1,583.4	2.0	8,967	4.4	4.7
Texas Bar, Ukiah	5	27	159	6.2	54	245.2	2.8	4	12	189	11.6	88	496.3	4.0	1,968	10.7	10.9
Wolf Creek, Baker	5	17	93	6.9	41	91.2	.4	2	2	204	16.3	91	115.5	18.9	501	35.5	35.5
Trout Farm, Prairie City	2	4	114	5.9	32	11.8	0	0	--	--	--	--	--	--	--	--	--
Total or average	28	141	119	7.5	52	1,153.2	3.3	34	151	154	16.9	93	10,166.5	5.4	50,345	11.1	11.8

1/ In board-foot measure, defect includes volume loss associated with decay, shake, frost cracks, and sound volume lost in cull logs. A cull log was one less than one-third sound.

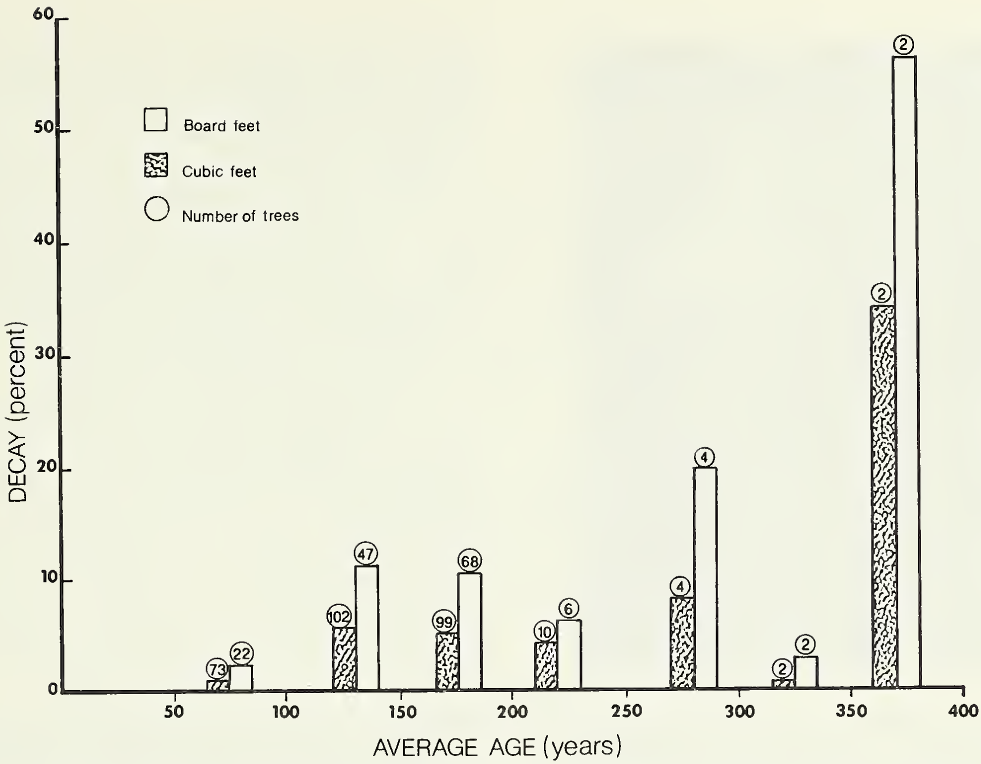

Figure 1.—Percent of cubic- and board-foot volumes decayed in Engelmann spruce by 50-year age classes.

Cyclic trends have been reported for Douglas-fir (Boyce and Wagg 1953) and subalpine fir (Hinds et al. 1960). As was the case in subalpine fir, it is likely that decay increases with age in Engelmann spruce stands until the most defective trees are eliminated by wind, beetles, root rot, or some other destructive agent. Decay percent in surviving trees is, therefore, lower. Decay then builds up in the stand until mortality of the most defective trees again lowers the decay percent for the stand. However, a larger sample in older age classes is necessary to confirm a cyclic decay-age relation in Engelmann spruce.

Root and butt rots.--Root and butt rots may be important contributors to the cyclic decay-age relationship in subalpine fir in Colorado (Hinds et al. 1960). They may kill trees directly or weaken them to the extent that insects finish them off. Mechanical weakening of roots and butts often results in windthrow or breakage (fig. 2). Root and butt rots occurred in 32 percent of all Engelmann spruce studied, whereas trunk rots were found in only 7 percent (table 2). Both types of rots appeared to become more prevalent with increasing tree age. However, root and butt rots do occur in a high percentage of young trees.

Diameter-decay relationship.--The incidence and severity of decay also usually increases with diameter, presumably because diameter is a function of age. Since diameter is easy to measure it may be more practical to relate decay to diameter

Figure 2.–Windbroken Engelmann spruce. Trees weakened by root and butt rot are commonly destroyed by wind and may contribute to cyclic relation between decay and age.

than to age. However, where all Engelmann spruce were sorted by diameter class (fig. 3), no consistent relationship between decay and diameter was found. This may be because Engelmann spruce is a tolerant species and often is suppressed for many years. Thus each diameter class has a wide range of ages. Percent decay based on cubic feet increased progressively from 0.9 percent in 5.0- to 6.9-inch diameter class to 5.3 percent in the 9.0- to 10.9-inch class. Then decay decreased in the 11.0- to 14.9-inch class to 5.0 percent, rising again to 7.5 percent in trees in the 15.0- to 18.9-inch diameter class. Decay then dropped to 3.4 percent in the 19.0- to 22.9-inch class, rising again in the 23.0- to 26.9-inch class to 7.3 percent. The cyclic nature of decay in Engelmann spruce is again suggested by these data; however, the sample of trees larger than 24-inch d.b.h. is too small to be conclusive.

Decay fungi.--Eleven fungi responsible for 75 percent of all infections and 80 percent of the decay cubic volume were identified by cultural methods or occasionally by appearance of the decay (table 3). Some fungi not identified are still being studied. White rot fungi were associated with more

Table 2.--*Root and butt and trunk rots in Engelmann spruce by age class*

Age class (years)	Tree basis	Trees in class with:	
		Root and butt rots	Trunk rots
	Number	*Percent*	*Percent*
50-99	73	25	3
100-149	102	26	5
150-199	99	39	11
200-249	10	50	10
250-299	4	75	0
300-349	2	50	0
350-399	2	100	50
Total	292	32	7

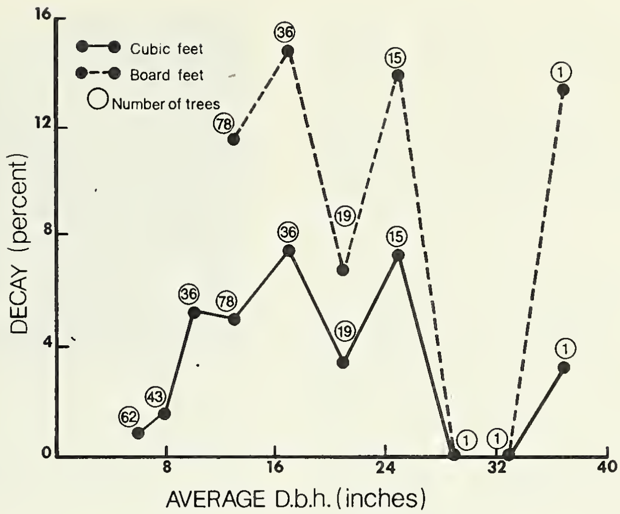

Figure 3.—Decay related to diameter of Engelmann spruce.

than 95 percent of all infections from which fungi were identified. Individual infections by four white root and butt rot fungi (*Polyporus tomentosus* var. *circinatus*, *Fomes annosus*, *Poria subacida*, and *Corticium galactinum*) accounted for nearly 60 percent of all infections and resulted in 42 percent of the decay cubic volume.

The most commonly occurring fungus was *Polyporus tomentosus* var. *circinatus* (fig. 4). Although this fungus alone was responsible for nearly 44 percent of all infections, it caused less than 10 percent of the decay cubic volume. This fungus caused only 4 percent of the identified infections in Engelmann spruce in Colorado (Hinds and Hawksworth 1966). Average decay volume per infection by *P. tomentosus* was only 1.1 cubic feet (table 3), compared with 3.1 cubic feet in the Colorado study.

Polyporus tomentosus var. *circinatus* appeared to occur in pockets or foci in the stand. Where this fungus was encountered, anywhere from a few to nearly all Engelmann spruce on a plot were infected. Infection apparently spreads from diseased trees to uninfected neighboring trees through roots. Dead and dying trees, indicating parasitic attack by this fungus, were not observed.

Fomes annosus (Fr.) Karst. was the second most commonly isolated fungus. Nearly 10 percent of all infections and approximately 14 percent of the decay cubic volume were attributable to this fungus. Usually two or three neighboring trees were infected, indicating tree-to-tree spread through roots.

Neither *F. annosus*, *Poria subacida* (Peck) Sacc., nor *Corticium galactinum* (Fr.) Burt was listed as causing decay in Engelmann spruce in either the Colorado or Alberta defect studies (Hinds and Hawksworth 1966, Etheridge 1956). In the present study, *C. galactinum* caused only three infections; however, extensive loss usually resulted.

Table 3.--*Fungi associated with decay of Engelmann spruce*

Fungus	Infections		Average decay volume[1]		Percent of total decay volume[1]	
	Number	*Percent*	*Cubic feet*	*Board feet*	*Cubic feet*	*Board feet*
White root and butt rots:						
Polyporus tomentosus Fr. var. *circinatus* (Fr.) Satory & Maire	50	43.8	1.1	30	9.6	12.3
Fomes annosus (Fr.) Karst.	11	9.6	7.4	115	13.7	12.3
Poria subacida (Peck) Sacc.	4	3.5	9.0	100	6.1	5.3
Corticium galactinum (Fr.) Burt	3	2.6	25.6	459	13.0	16.3
White trunk rots:						
Stereum sanguinolentum (Alb. & Schw. ex Fr.) Fr.	5	4.4	7.9	199	6.7	7.0
F. pini (Brot. ex Fr.) Karst.	3	2.6	30.2	218	15.3	11.6
S. chailletii (Pers. ex Fr.) Fr.	2	1.8	13.7	125	4.6	4.4
Polyporus versicolor L. ex Fr.	1	.9	.4	1	.1	([2])
Brown trunk rots:						
Peniophora spp.	1	.9	7.2	66	1.2	1.1
Trechispora raduloides (Karst.) Rogers	1	.9	5.4	--	1.0	--
Mixed[3]	5	4.4	10.3	103	8.7	9.2
Unidentified	28	24.6	4.2	52	20.0	20.5
Total	114	100.0	--	--	100.0	100.0

[1] Infections in pole and sawtimber size trees are included under cubic-foot measurement, but only infections in trees larger than 11.0-inch d.b.h. are included under board-foot measurement.

[2] Less than 0.5 percent of the total board-foot decay volume.

[3] Fungi associated in mixed infections as determined by cultural techniques:

P. tomentosus var. *circinatus* - *S. sanguinolentum* (2 occurrences)
P. tomentosus var. *circinatus* - *Poria subacida*
P. tomentosus var. *circinatus* - *T. raduloides*
Trametes serialis (Fr.) - *S. sanguinolentum*.

Figure 4.–*Polyporus tomentosus* var. *circinatus* root and butt rot of Engelmann spruce. Although diameter of decay column was very large at stump height, it usually extended only a few feet into the butt log.

Identified trunk rotting fungi caused only 12 percent of all infections, but these resulted in nearly 30 percent of all cubic volume decay loss. The ring scale fungus, *F. pini*, was responsible for only three infections; however, a loss of 15 percent of the total cubic volume resulted. This fungus was the most important fungus encountered in the Colorado and Alberta studies (Hinds and Hawksworth 1966, Etheridge 1956). Although *F. pini* infections resulted in extensive decay columns, no conks were produced on infected trees. This fungus commonly develops punk knots on Engelmann spruce in Colorado (Hinds and Hawksworth 1966).

Stereum sanguinolentum was isolated from eight trees--five individual infections and three in mixture with other fungi. This important slash-rotting fungus caused many infections in Engelmann and subalpine spruce in Colorado and Alberta, respectively. *Flammula connissans*, *Coniophora puteana*, *Peniophora septentrionalis*, *Fomes nigrolimitatus*, *Pholiota alnicola*, and *Corticium radiosum* were commonly associated with decay columns in the Colorado and Alberta studies (Hinds and Hawksworth 1966, Etheridge 1956) but were not isolated or identified in Engelmann spruce in this study.

Infection courts for fungi.--The important infection courts for fungi attacking Engelmann spruce are listed in table 4.

Table 4.--*Apparent infection courts for fungi attacking Engelmann spruce*

Fungus	Infection court								
	Roots	Basal injuries	Trunk wounds	Frost cracks	Forks	Crooks	Dead vertical branches	Crook and dead vertical branch	Broken tops
	Number								
Polyporus circinatus	50	0	0	0	0	0	0	0	0
P. versicolor	0	0	0	0	0	0	0	0	1
Fomes annosus	7	2	1	1	0	0	0	0	0
F. pini	0	1	0	0	1	1	0	0	0
Poria subacida	2	2	0	0	0	0	0	0	0
Corticium galactinum	2	0	1	0	0	0	0	0	0
Stereum sanguinolentum	0	1	0	0	1	1	0	0	2
S. chailletii	0	1	0	0	0	1	0	0	0
Peniophora spp.	0	0	0	0	0	0	0	1	0
Trechispora raduloides	1	0	0	0	0	0	0	0	0
Unidentified	12	7	3	2	0	0	1	1	2
Total infections[1/]	74	14	5	3	2	3	1	2	5

[1/] Does not include entrance courts for five mixed fungal infections.

Roots and basal injuries including frost cracks were apparent entry points for 91 of 109 infections (mixed fungal infections are not included). Roots were the most common entrance courts for identified as well as unidentified fungi. All individual *Polyporus tomentosus* var. *circinatus* infections took place through roots. *Fomes annosus*, however, infected trees through roots and also through injuries, usually on the tree butt. Trunk decaying fungi such as *F. pini*, *Stereum sanguinolentum*, and *S. chailletii* attacked trees through injuries as was common in the Colorado study (Hinds and Hawksworth 1966). Branch infections by *F. pini* with subsequent production of swollen knots or conks were not found here. However, conks and punk knots were frequently found on Engelmann spruce in Colorado (Hinds and Hawksworth 1966). Dead tops associated with rust infections, important infection courts in Colorado, were not found in the Blue Mountains although an occasional large witches'-broom caused by a rust fungus was observed in some study trees.

A trunk rotting fungus, *Trechispora raduloides* (Karst.) Rogers, was isolated from what appeared to be a root and butt rot. It was not possible to determine whether the infection had taken place through a branch or through an old injury.

DEFECT INDICATORS AND ESTIMATING PROCEDURES

Factors for defect indicators are given as: (1) percentages of gross merchantable cubic- and board-foot tree volumes as reported by Aho (1966), and (2) average length deductions below and above indicators with flat percentage factors for hidden defect. Many Engelmann spruce did not have visible indicators of decay, partly because nearly 70 percent of the individual fungal infections entered trees through roots (table 4). No fungi produced punky or swollen knots or conks. Therefore, indicator factors are for less reliable types, mainly injuries, including basal and trunk wounds, frost cracks, and broken tops.

The most reliable defect indicators were basal injuries (fig. 5). They are open or healed wounds in contact with the ground and may be caused by fire, falling trees, logging machinery, or rubbing or chewing by animals.

Frost cracks or seams are open or closed wounds (fig. 6) probably caused by freezing. They are not included as indicators of decay for cubic volume defect percentages but are included for board feet, because the frost crack itself is a deductible defect.

Trunk injuries (fig. 7) are open or closed wounds below the merchantable top but not in contact with the ground. Wounds less than 1 foot long or less than 5 years old should be ignored since there is seldom extensive decay associated with them.

Broken tops (fig. 8) below merchantable top diameter are also indicators of defect. No dead tops were encountered on study trees.

Percentage factors for defect indicators.--The following equations estimate defect in individual trees on a cubic- and board-foot basis and are repeated here for convenience (Aho 1966).

Cubic feet:

$$P_c = -5.108 + 0.046A + 13.126B + 0.139D + 1.798E + 6.150T \quad (1)$$

$$P_c = -1.124 + 13.696B + 0.324D + 2.032E + 6.587T \quad (2)$$

Board feet:

$$P_b = -4.909 + 0.097A + 35.814B - 0.100D + 6.013E + 3.542F + 30.201T \quad (3)$$

$$P_b = 3.837 + 37.464B + 0.271D + 2.640E + 2.522F + 35.529T \quad (4)$$

Where

P_c = percent of gross merchantable cubic-foot volume that is cull.

P_b = percent of gross merchantable board-foot volume that is cull.

A = tree age.

B = 1 if one or more basal injuries present; 0 if no basal injury present.

D = tree diameter outside bark at breast height.

E = 1 if broken top present; 0 if no broken top present.

F = 1 if one or more frost cracks present; 0 if no frost cracks present.

T = 1 if one or more trunk injuries longer than 1 foot present; 0 if no trunk injuries present.

To provide a quick reference for use in the field, tables 5 and 6 were developed from equations 1 and 3. Familiarity with the indicators (figs. 5A, 6A, 7A, and 8A) aids in effective application of the given defect percentages. Defect percentages are presented for individual and combinations of indicators. Procedure would be as follows. Injuries less than 5 years old are ignored because decay development is seldom extensive behind recent wounds. D. b. h. is measured, age roughly estimated, and the presence of appropriate indicators noted. From these, defect percentages from the proper table can be read. For example, a 20-inch, 225-year-old Engelmann spruce with no indicators would have deductions of 8 percent of its total cubic-foot volume (table 5) and 15 percent of its board-foot volume (table 6). A 12-inch, 125-year-old Engelmann spruce with a top injury and basal injury would have deductions of 17 percent in cubic feet (table 5) and 48 percent in board feet (table 6).

Table 5.--*Percentages of gross merchantable cubic-foot volume cull in Engelmann spruce, by d.b.h., age, and indicator class*[1]

Indicator class	D.b.h. class and age (years)											
	8 inches		12 inches			20 inches			28 inches			
	75	125	75	125	175	125	175	225	125	175	225	275
	Percent											
No indicators	0	2	0	2	5	3	6	8	5	7	9	11
Top injuries	1	4	2	4	6	5	8	10	6	9	11	13
Trunk injuries[2]	6	8	6	8	11	10	12	14	11	13	15	18
Basal injuries[2]	13	15	13	15	18	17	19	21	18	20	22	25
Top and trunk injuries[2]	7	10	8	10	13	11	14	16	12	15	17	19
Top and basal injuries[2]	14	17	15	17	20	18	21	23	19	22	24	26
Trunk and basal injuries[2]	19	21	19	22	24	23	25	27	24	26	28	31
Top, trunk, and basal injuries[2]	21	23	21	23	26	24	27	29	26	28	30	33

[1] Derived from equation 1,

$$P_c = -5.108 + 0.046A + 13.126B + 0.139D + 1.798E + 6.150T,$$

where A = tree age; B = 1 if one or more basal injuries present, 0 if no basal injury present; D = tree diameter outside bark at breast height; E = 1 if broken top present, 0 if no broken top present; and T = 1 if one or more trunk injuries longer than 1 foot present, 0 if no trunk injuries present.

[2] No deduction for frost cracks.

Table 6.--*Percentages of gross merchantable board-foot volume cull in Engelmann spruce, by d.b.h., age, and indicator class*[1]

Indicator class	D.b.h. class and age (years)									
	12 inches			20 inches			28 inches			
	75	125	175	125	175	225	125	175	225	275
	Percent									
No indicators	1	6	11	5	10	15	4	9	14	19
Frost cracks	5	10	14	9	14	18	8	13	18	23
Top injuries	7	12	17	11	16	21	10	15	20	25
Trunk injuries	31	36	41	35	40	45	35	39	44	49
Basal injuries	37	42	47	41	46	51	40	45	50	55
Frost cracks and top injuries	11	16	20	15	20	24	14	19	24	29
Frost cracks and trunk injuries	35	40	45	39	44	49	38	43	48	53
Top and trunk injuries	37	42	47	41	46	51	41	45	50	55
Frost cracks and basal injuries	41	45	50	45	49	54	44	49	53	58
Top and basal injuries	43	48	53	47	52	57	46	51	56	61
Trunk and basal injuries	67	72	77	71	76	81	70	75	80	85
Frost cracks, top, and trunk injuries	41	46	51	45	50	55	44	49	54	59
Frost cracks, top, and basal injuries	47	51	56	51	55	60	50	55	59	64
Frost cracks, trunk, and basal injuries	71	76	80	75	80	84	74	79	84	89
Top, trunk, and basal injuries	73	78	83	77	82	87	76	81	86	91
Frost cracks, top, trunk, and basal injuries	77	82	86	81	86	90	80	85	90	95

[1] Derived from equation 3,

$$P_b = -4.909 + 0.097A + 35.814B - 0.100D + 6.013E + 3.542F + 30.201T,$$

where A = tree age; B = 1 if one or more basal injuries present, 0 if no basal injury present; D = tree diameter outside bark at breast height; E = 1 if broken top present, 0 if no broken top present; F = 1 if one or more frost cracks present, 0 if no frost crack present; and T = 1 if one or more trunk injuries longer than 1 foot present, 0 if no trunk injuries present.

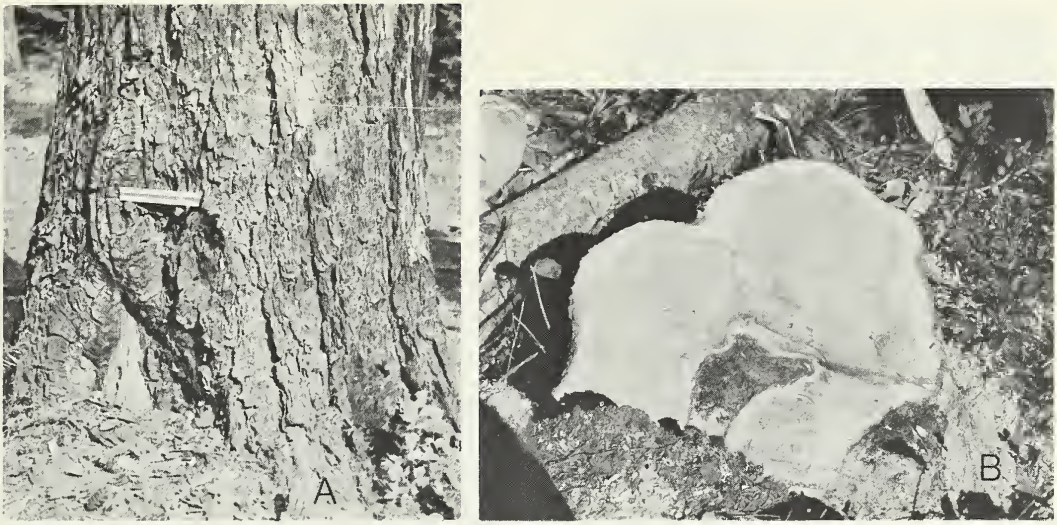

Figure 5.—*A*, Basal injury in Engelmann spruce (these indicators are sometimes inconspicuous and may be overlooked); *B*, decay associated with basal wound.

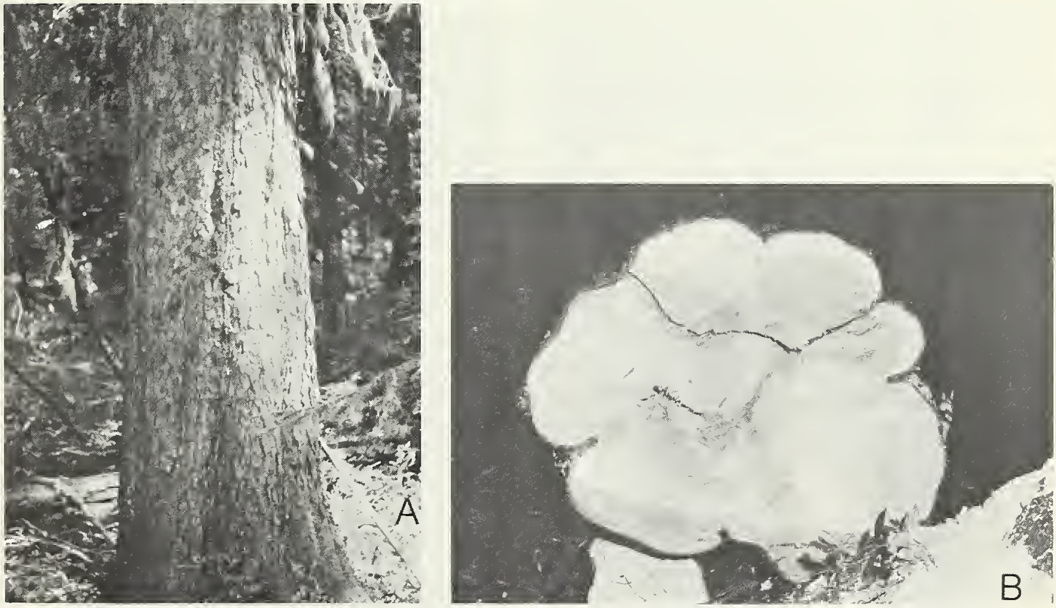

Figure 6.—*A*, Frost crack or seam on Engelmann spruce; *B*, decay associated with frost crack.

Figure 7.—*A*, Trunk injury in bole of Engelmann spruce; *B*, decay associated with old trunk injury.

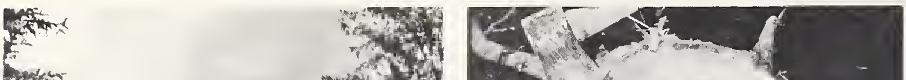

Figure 8.—*A*, Broken top below merchantable top diameter indicates decay in Engelmann spruce; *B*, decay associated with broken top.

Equations 2 and 4 are included for use when age is not determined. These equations may be used to generate tables similar to those presented above.

Length deductions for indicators and flat factors for hidden defect.--Some timber cruisers prefer to use average length deductions below and above indicators to determine net tree volumes. Length deductions for commonly occurring defect indicators on Engelmann spruce are in table 7. All defect within the dimensions of the wound and that extending below and above, when appropriate, are included in the length deduction. Decay columns associated with indicators on the bole that extend into roots, broken tops, or another rot column are not included in the average deductions. Since, in most instances, there is no way of determining which injuries have associated decay, the average deductions for a given indicator class should be applied to all indicators of that class encountered, except recent injuries, i.e., those less than 5 years old, and trunk scars less than 1 foot long.

Hidden defect includes decay associated with indicators of minor importance and that caused by fungi which enter trees through roots or branches and produce no indicators such as conks. Minor indicators include crooks, forks, dead vertical branches, and trunk wounds less than 1 foot long. At times decay may be associated with these indicators, but this is so infrequent or so limited that it is probably best to include it as a flat percentage factor for hidden defect.

Total net cubic- and Scribner board-foot volumes, determined by application of average length deductions for indicators to individual trees, must be further reduced for hidden defect by 3 and 7 percent, respectively.

Application of length deductions for indicators and hidden defect percentage factors should be in the following manner. Net volumes of all sample trees are calculated, using the indicator length deductions where appropriate. After net tree volumes are totaled, the appropriate flat percentage factor (i.e., 3 percent to net cubic-foot volumes and 7 percent to net board-foot volumes) is applied to the total net sample volume. Sound net sample volume is thus obtained, excepting deductions for sweep, breakage in logging, and missing parts of trees such as broken tops or portions of butt logs burned away by fire.

Table 7.--*Length deductions for defect indicators on Engelmann spruce sawtimber*

Indicator	Frequency of infection	Average length deduction	
		Below	Above
	Percent	*Feet*	
Basal injuries	92	--	10
Trunk wounds	44	1	3
Frost cracks	36	--	2
Broken tops	40	3	--

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